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Evaluating the Quality of Water Treated by Redwood Slat Tower Aerators

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The aerators were 50 to 95 percent efficient for removing the volatile organic compounds. Both standard plate counts and coliforms increased through the aerators, but Legionella was not isolated in the unaerated or aerated water. Precipitation of iron and the subsequent buildup of sludge on the distribution plate inside the aerators at one site decreased the efficiency for removing volatile organic compounds. These experiences underscore the need for routine attention and maintenance on any treatment process.

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ABSTRACT

Over a two year period, the U.S. Environmental Protection Agency, Drinking Water Research Division (EPA-DWRD), and two New England water utilities evaluated the water quality from redwood slat tower aerators. Samples of aerator influent and aerator effluent were analyzed for several volatile organic compounds, some of which are being considered for possible regulatory action (1). The two principal organics in the waters were trichloroethylene and cis-1,2-dichloroethylene; the sum of the concentrations ranged from 9 to 300 micrograms per liter (ug/L). In addition, fourteen inorganic compounds [seven of which have maximum contaminant levels (2)] and three microbiological parameters (standard plate count, total coliforms, and Legionella) were routinely monitored.

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INTRODUCTION

The advent of the volatile organic analysis (VOA) for water in late 1974 (3) allowed many water works personnel to detect, for the first time, microgram per liter (ug/L) concentrations of organic chemicals in their product. With the VOA, came a concern for a particular group of compounds that are created upon chlorination, the trihalomethanes. Some utilities, eager to demonstrate the absence of trihalomethanes in their ground water sources, learned through the VOA that their well water contained not trialomethanes, but various industrial solvents, such as tri- and tetrachloroethylene.

When faced with the loss of a well because of organic contamination and alternative sources of water were not practical, some utilities installed aerators to strip the volatile organic compounds from the water. This paper describes a two year program conducted jointly by EPA-DWRD and two New England water utilities evaluating the water quality from redwood slat tower aerators. More specifically, one of the objectives of this project was to examine the efficiency of stripping volatile organic compounds with both a housed (i.e. protected from the weather) and unhoused aerator.

Redwood is known to contain soluble nutrients and because redwood storage tanks have been shown to support bacteriological growth (4), the seasonal bacteriological quality of the aerated water was closely monitored. In particular, because of the similarity between these aerators and cooling towers, and because Legionella have been isolated from cooling tower water (5), the waters were scrutinized for this bacterium.

STUDY SITES

The two communities participating in this study were Norwalk, Connecticut and Wilmington, Massachusetts. The wells for the City of Norwalk are located adjacent to the Norwalk River and in 1977, contamination by industrial solvents (mainly trichloroethylene) was discovered in one of their high volume production wells. The source of the contamination is thought to be an abandoned landfill on the opposite side of the River, but this has not been confirmed. In 1981, Norwalk installed an unhoused redwood slat aerator next to their contaminated well. The well is normally only operated during peak demand periods to augment their primary source, which is surface water from upland reservoirs. The water from the aerator discharges into a sealed caisson well that serves as a clearwell. The aerated water is mixed with water from other wells, chlorinated and repumped into the distribution system.

The City of Wilmington was in the process of having a new water treatment plant designed (May 1979) when volatile organic compounds from an unknown source were discovered in some of their wells. The plans already included two redwood slat tower aerators to control carbon dioxide and iron, so, when organic solvents were identified in the source water, the design engineers conducted some simple aeration tests and decided to increase the size of the proposed aerators, add additional redwood slats and double the volume of air flow (6). The Wilmington water treatment plant was commissioned in the summer of 1981 and is quite unique. The well water, after aeration, is further treated with alum, lime, a polyelectrolyte, and potassium permanganate. The water then passes through a sedimentation basin having 60° inclined tube settlers and filtered through 1.2m of lignite base granular activated carbon. The original plans called for mixed media filters, but activated carbon was substituted in the revised plans as a "polishing step" for the volatile organic compounds. The aerators are housed within the filter plant building. This water treatment plant is not run continously. Operation is daily, but only long enough to satisfy water usage and storage demands. This generally take 12 to 20 hours.

The aerators at both study sites are described in more detail in Table 1. A photo of the Norwalk unit is shown in Figure 1 and a schematic drawing of a typical redwood slat tower aerator is illustrated in Figure 2. Water is pumped into the top of the aerator, distributed over the cross-sectional area by a perforated plate, and allowed to trickle down and over the redwood slats. The slats are staggered to prevent the water from short circuiting. Air is pulled into the bottom of the tower by fans mounted on top (i.e., induced draft). The air travels upward counter-current to the water flow. In this fashion, a large volume of air is contacted with a relatively small volume of water, thus allowing volatile organic compounds to be transferred from the water to the air and exhausted out the top of the tower. The monitoring protocol and testing procedures are described in the following section.

SAMPLE COLLECTION AND ANALYSES

Samples were collected by water works personnel in containers furnished by EPA-DWRD. In Norwalk, samples of aerator influent (contaminated well water) and aerator effluent were collected on a variable schedule because the contaminated well and aerator were only in service when water demands peaked. At times, however, the water works personnel ran the system to waste to accommodate our seasonal sampling scheulule. At Wilmington, in addition to sampling in and out of the aerator, other sample locations included: a. after coagulation and settling, and, b. after filtration/adsorption on granular activated carbon. Sampling at Wilmington was weekly for organic and inorganic quality monitoring, but the schedule varied for microbiological sampling. For the latter, efforts were much more intense during warm weather and immediately after start-up. The chemistry samples were mailed first class and the microbiological samples were iced and air freighted to the EPA-DWRD Laboratory in Cincinnati, Ohio for the following analyses:

Organic Procedures

Water samples for volatile organic compounds were collected headspace-free in 40 milliliter (mL) screw cap vials with Teflon®* lined septa. These samples were analyzed according to EPA Method 601 (7), the purge and trap procedure using a Hall electrolytic conductivity detector. Total organic carbon analyses** were performed on a Dohrmann DC-54 ultra low TOC analyzyer.

Inorganic Procedures

Water samples for inorganic characterization were collected in two, one liter polyethylene cubitainers with plastic inserts and screw tops. One of the two cubitainers contained 1.5 mL of nitric acid as a preservative. This procedure allowed a wide range of inorganic analyses to be performed. These samples were analyzed according to approved EPA methods (8).

Microbiological Procedures

Water samples for microbiological quality were collected in sterile one-liter polyethylene bottles. Several samples of scrapings from the redwood slats were also collected and placed in a 100 mL screw cap vial. Heterotrophic bacteria were enumerated by a. the pour plate technique using standard plate count agar (9); b. a low nutrient media designated R2A (10); and, c. the membrane filtered standard plate count (MSPC) (11). Analyses for total coliform bacteria were conducted by membrane filtration using M-Endo agar (9). All isolates from M-Endo were speciated using the API 20E† system. Influent and effluent aeration samples were examined once per month for the occurrence of Legionella. Details on culturing procedures and identification techniques for this organism may be found in Reference 12.

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*Mention of commercial products does not constitute approval or endorsement by the U.S. EPA.

**UV promoted persulfate method as per Dohrmann DC-54 instrument manual, Dohrmann Division, XERTEX, Santa Clara, CA.

†Analytab Products, Plainview, NY

RESULTS AND DISCUSSION

Organic Quality

The aerators had been in service for 5 months at Wilmington and for 6 months at Norwalk when the EPA-DWRD water quality evaluation project started. Table 2 lists the organic quality of the influent water to the aerators at both sites. Note, trichloroethylene and cis-1,2-dichloroethylene are the predominant compounds. In Norwalk, the aerator consistently removed about 65 percent of the volatile organic compounds (Table 3). This produced a water containing less than 40 ug/L of volatile contaminants.

Figure 3 shows the total volatile organic compounds concentrations (arthimetic sum in ug/L of all volatile constituents other than trihalomethanes) in each sampling point throughout the Wilmington water treatment plant over the course of the project. Table 3 shows the efficiency of aeration, coagulation and settling, and filtration/adsorption through granular activated carbon at Wilmington. Also shown are the cumlative removals through the treatment processes. The aeration efficiency for removing the volatile organic compounds ranged from 90 to 95 percent. This produced a water containing less than 20 ug/L of volatile organic compounds. Recall from Table 1, the Wilmington aerators have a much higher air-to-water ratio than the Norwalk aerator, so a high stripping efficiency would be expected.

Aeration efficiency at Wilmington decreased, however, to 50 to 70 percent during the summer of 1983 (Figure 3, after approximately 750 days of operation). Upon inspection the aerators were found to be clogged with iron sludge. This is described in more detail later in this paper. A slight decrease in efficiency (see Figure 3, day 460) also occurred when one of the aeration blowers was being repaired. As has been reported elsewhere (13), little removal of the volatile organic compounds was noted through the coagulation and settling step, but the granular activated carbon was very effective for the first year of operation.

A six-week-long special study was conducted at Wilmington, wherein the aeration efficiency calculated from grab sample data was to be compared to the efficiency derived from 5-day composite sample data. The devices used to collect the headspace free composite water samples were those described by Westrick and Cummins (14). The concentrations of volatile organic compounds in the influent composite samples were consistently about 20 percent lower than the concentrations found in the companion influent grab samples. The concentrations of organics in the effluent samples, however, were nearly identical to each other. This raised a question about the integrity of the influent composite sampler and no further comparisons were made.

In summary, despite variations in the influent concentrations of volatile organic compounds, and fluctuations in air temperatures during cold and hot weather, the efficiency of aeration was not significantly affected at either site. The temperature of the ground water averaged 11°C and the water temperatures before and after aeration varied less than 1°C year-round at both the housed and unhoused installations.

Inorganic Quality

At Norwalk, except for the expected slight increase in pH, little difference was observed (Table 4) in the inorganic quality of the pre- and post-aerated water. Table 4 also shows the average inorganic quality of the water at each sampling point in the Wilmington treatment system. The results indicate little or no difference in the inorganic quality of the pre- and post-aerated water for turbidity, total dissolved solids, chloride, sulfate, sodium, arsenic, fluoride, hardness, alkalinity, specific conductance, chromium, silver, manganese, lead, cadmium, zinc, and mercury. Removals were noted for color (23%), copper (76%) and iron (21%). The pH increased from 6.7 to 7.2, probably the result of removing carbon dioxide. Coagulation and settling, as expected, did not affect background concentrations of chloride, sodium, arsenic, fluoride, alkalinity or mercury, but because of chemicals added for "treatment" the following parameters increased: turbidity (21%), sulfate (42%), hardness (25%), and manganese (12%). Coagulation and settling did however, remove an additional 65 percent of the color and iron and, as expected, the granular activated carbon filter removed a high percentage of the carry over turbidity manganese and iron.

Microbiological Quality

Most of the microbiological sampling was carried out during the warmer months. A comparison of the mean bacterial populations in the raw and aerated water is given in Table 5. From the Norwalk aerator, some increases were observed in coliform concentrations, but the general bacterial populations were not markedly different in pre- and post-aerated water. The highest bacterial populations generally occurred shortly after aerator start-up indicating a hydraulic sloughing off of colonies.

In Wilmington, the general bacterial populations increased during aeration. Note from Table 5, the Wilmington bacteriological data is divided between the sample results up to day 750 and the data from day 750 to day 850. Increasing bacterial populations after day 750, combined with declining removal efficiencies for the volatile organic compounds during the same period (Figure 3), are indications of maintenance problems. Bacteria were possibly colonizing on the redwood slats, but most of the biological activity was probably associated with precipitated inorganic sludge, a problem described in the next section.

Legionella was not isolated in any of the water samples at either site. Klebsiella a coliform, was identified in the aerated water. Details of this work are reported elsewhere (13).

Maintenance

After approximately two years of operation, the efficiency of aeration at Wilmington began declining and deterioration in the bacteriological quality of the aerated water became evident. These redwood slat aerators were built without inspection ports, so routine examination of the internal appearance of these devices is very difficult as it requires removing a part of the aluminum shell. This is definitely a shortcoming in the design of these units. When the Wilmington water works personnel removed the sides from the aerators, they found iron sludge had accumulated several centimeters thick (15 to 20 cm) on the distributor plate. This sludge was blocking the exits holes and the water was being short circuited down the sides of the aerator. In retrospect, a review of the inorganic data (Table 4) shows approximately

0.2 mg/L of iron was being removed through aeration. Over the course of a year of continous running, between 400 and 500 kg of iron would be exepcted to accumulate in each unit. At Wilmington, the operators used fire hoses to wash down the iron sludge and now have an annual maintenance program for cleaning the interiors of their aerators.

SUMMARY

These experiences amplify the importance of the laboratory's role in water treatment. That role is much more than characterizing the raw and finished water for compliance with drinking water regulations and day-to-day operations. When reviewed in toto, discrete organic, inorganic, and microbiological analyses before and after treatment can detect the onset of maintenance problems. This is critical when dealing with treatment devices, such as these aerators, that were not designed to be easily inspected.

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TABLE 1

DESCRIPTION OF REDWOOD SLAT AERATORS

	Norwalk, CT	Wilmington, MA
Fabricated by:	Laynco Environmental Products Layne New England Company Arlington, MA 12174	General Filter Ames, Iowa 50010
Date of Installation	May 1981	June 1981
Construction Material	aluminum	aluminum
Number of aerators	one	two, in parallel
Dimensions	3m x 4m x 5m (high) (10ft x 12ft x 16ft)	3m x 3m x 5 m (high) (10ft x 10ft x 15ft)
Internals	redwood slats on 12.5 cm centers	redwood slats on 5 cm centers
Water Flow	4 m^3/min (1,000 gpm)	4 m^3/min (1.5 mgd)/ aerator @ max water flow 2 m^3/min (0.75 mgd)/ aerator @ avg. water flow
Air Flow	one fan located on top; 110 m^3/min (3,900 cfm)	two fans/aerator located on top; 104 m^3/min (3,700 cfm)/fan each or 208 m^3/min/aerator
Air to water ratio (vol to vol)	29:1	50:1 @ max water flow 100:1 @ avg water flow
Effluent from aerator	discharged into a sealed caission well, repumped and chlorinated	followed by coagulation, settling, and filtration through granular activated carbon

TABLE 2

ORGANIC QUALITY OF UNTREATED WATER (AERATOR INFLUENT)

	Concentration, ug/L			
	Norwalk, Conn.		Wilmington, Mass.	
Parameter	Mean	Range	Mean	Range
Trichloroethylene	41.2	7.2 - 142.1	93.9	8.4 - 283.7
cis-1,2-Dichloroethylene	4.6	<0.1 - 12.1	9.6	2.3 - 19.7
Tetrachloroethylene	1.2	<0.1 - 3.5	1.0	<0.1 - 2.9
1,2-Dichloroethane	0.1	<0.1 - 0.8	0.3	<0.1 - 2.7
1,1,1-Trichloroethane	0.5	<0.1 - 1.4	0.9	<0.2 - 2.3
1,1-Dichloroethane	0.2	<0.2 - 1.3	0.3	<0.1 - 2.1
1,1-Dichloroethylene	0.1	<0.1 - 1.2	0.4	<0.1 - 1.7
Total Organic Carbon (TOC)	1,500	1,300 - 2,000	3,900	3,400 - 4,830

TABLE 3

EFFICIENCY OF REMOVAL OF VOLATILE ORGANIC COMPOUNDS

Norwalk, CT	
Date	Aeration Only
1981-1983	65%

Wilmington, MA			
Date	Aeration Only	Aeration + Coagulation/ Settling	Aeration + Coagulation/Settling + GAC Filtration/ Adsorption
Fall 1981-Fall 1982	91%	91%	98%
Aug. 1982-Sept. 1982 (blower down)	74%	73%	99%
Fall 1982-Spr 1983	89%	89%	96%
Spr 1983-Fall 1983 (clogged aerator)	64%	(insufficient data)	97%
Fall 83 (aerator cleaned)	91%	91%	92%

TABLE 4

AVERAGE INORGANIC WATER QUALITY BEFORE AND AFTER TREATMENT

Parameter*	Norwalk, CT		Wilmington, MA			
	Aeration		Aeration		Filtration/ Adsorption	
	Before	After	Before	After	Before**	After
Turbidity, ntu	0.2	0.2	1.8	1.6	2.0	0.24
Color, units	2.6	3.6	16.6	12.8	4.6	3.7
T.D.S.	144	145	190	185	199	200
Chloride	26	25	50	50	50	52
Sulfate	22	22	33	33	47	46
Sodium	15	15	28	28	26	28
Arsenic	0.005	0.005	0.005	0.005	0.005	0.005
Fluoride	0.1	0.1	0.1	0.1	0.1	0.1
Hardness, as $CaCO_3$	81	81	70	71	88	81
Alkalinity, as $CaCO_3$	53	56	23	24	20	19
Specific Conductance, umhos/cm	251	254	314	313	330	335
pH, units	7.4	7.6	6.6	7.2	7.1	7.1
Chromium	0.005	0.005	0.005	0.005	0.005	0.005
Silver	0.03	0.03	0.03	0.03	0.03	0.03
Copper	0.02	0.02	0.08	0.02	0.02	0.04
Manganese	0.03	0.03	0.36	0.34	0.39	0.10
Lead	0.005	0.005	0.005	0.005	0.005	0.005
Iron	0.1	0.1	1.3	1.0	0.3	0.1
Cadmium	0.002	0.002	0.002	0.002	0.002	0.002
Zinc	0.03	0.03	0.02	0.02	0.02	0.02
Mercury	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

*All concentrations in mg/L except as noted.

**After coagulation and settling

TABLE 5

BACTERIOLOGICAL QUALITY BEFORE AND AFTER AERATION

	Heterotrophic Plate Count/mL		Total Coliforms/100 mL	
Norwalk, CT	Range	Mean*	Range	Mean**
Before	< 1 - 57,900	(222)	< 1 - 6	(2)
After	24 - 4,900	(188)	< 1 -342	(17)
Wilmington, MA				
a. Before	1 - 103	(8)	< 1 - 2	(< 1)
After	< 1 - 18,100	(40)	< 1 - 10	(2)
b. Before	< 1 - 5,100	(50)	< 1 - 2	(< 1)
After	< 1 - 15,400	(188)	< 1 - 37	(5)

* geometric
**arithmetic
a - Up to 750 days of service
b - Between 750 and 850 days of service (see text for explanation)

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Figure 1. Redwood Slat Tower Aerator, Norwalk, CT.

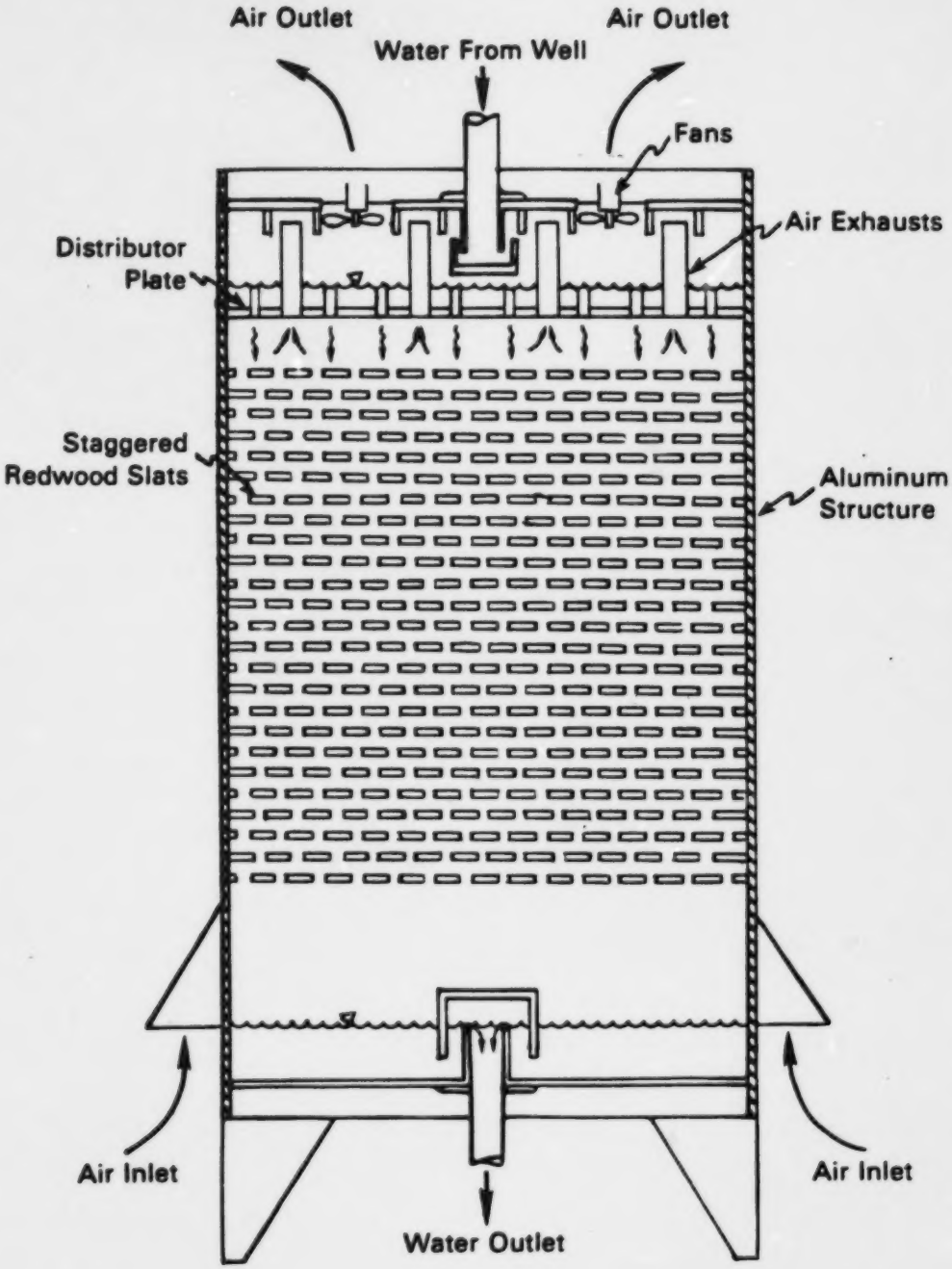

Figure 2. Typical Redwood Slat Tower Aerator.

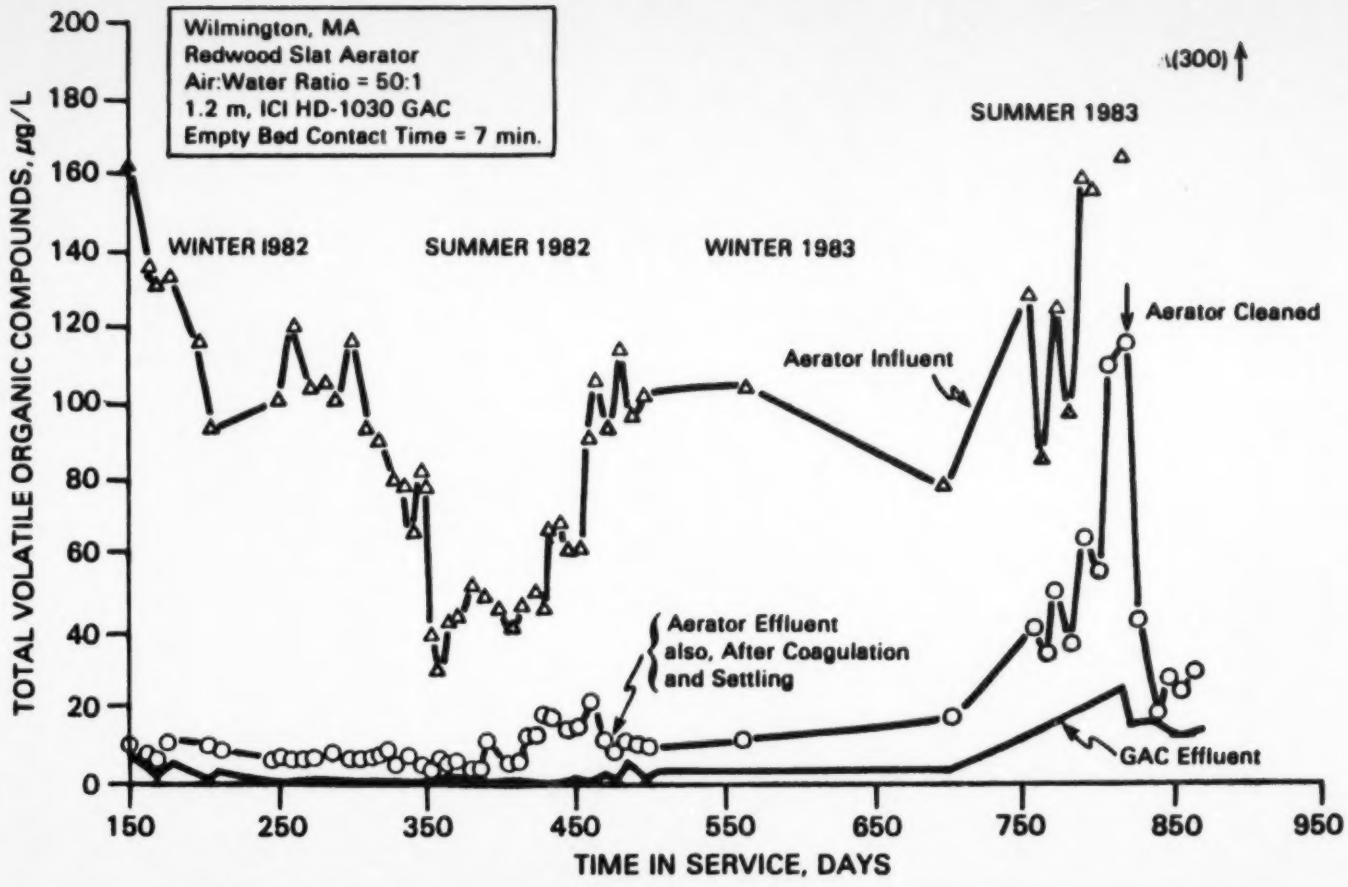

Figure 3. Removal of Volatile Organic Compounds by Aeration, Coagulation and Settling, and Filtration/Adsorption on Granular Activated Carbon.